RESPONSE OF SULPHUR NUTRITION IN MUSTARD - A REVIEW
R.S. Chandel, P.C. Sudhakar and Kalyan Singh
Department of Agronomy, Institute of Agricultural Sciences
Banaras Hindu University, Varanasi - 221 005, India

ABSTRACT
Sulphur is an essential nutrient for all the plants. It is constituent of essential amino acids (cysteine, cystine and methionine), several coenzymes (biotin, coenzyme A, thiamine pyrophosphate, lipoic acid and thioredoxin) and sulpholipids. Application of sulphur fertilizers to rapeseed and mustard can lead to increased glucosinolate content in seed which leads to higher content its cake that harmful as animal feed. It has important role in improving the quality and marketability of produce (seed & oil). The quality decides the market price and output of the end product i.e. oil per unit of economic yield. Sulphur application increases glucosinolate, protein and glucoside. Increase in seed yield of rapeseed and mustard have been reported due to varying levels of sulphur fertilization depending upon its deficiency in soil. Besides other benefits adequate sulphur is required for reduction of nitrate, in nitrogen metabolism and increased chlorophyll content in leaf. Sulphur application increases plant height, leaves plant", dry matter production besides increasing yield attributes and yield of mustard. Oil content, protein content and nutrient content increases with increasing sulphur application depending upon the sulphur status of the soil. Residual effect of sulphur is more pronounced at higher levels of sulphur application in mustard based cropping system.

Oils and fats are essential constituents of our food, besides having many other industrial uses. In India the oilseed crops share 13% of the total cropped area and contribute substantially to the national income. Presently, India produces 22 mt of oilseed from 25.5 mha (Singh, 1999). The inherent biological limitation for such a low yield of oilseeds has been attributed to several constraints and nutrient deficiency, particularly of sulphur is one of the major constraints. Oilseeds are mainly grown in coarse textured soils, which are low in total soil sulphur, where as sulphur accounts for 0.1 to 0.5 % dry weight of the oilseeds where it is present both in organic and inorganic compounds. The sulphur uptake is slightly lower than phosphorus. The sulphur is mainly taken up by plant through roots as sulphate. The sulphur contents of the oilseed vary with the plant parts and are higher in grain. Both the concentration of sulphur in plant parts and N:S ratio have been used for determining the critical levels of sulphur application to oilseed crops. Rapeseed and mustard require at least 0.33 to 0.40% sulphur in leaf for obtaining 90% of its potential yield (Cheema and Arora, 1984).

Effect on Growth
Sulphur has some specific role in oilseed crops. Sulphur deficiency results in accumulation of amides and carbohydrates and in turn, retards the formation of chlorophyll and causes stunted plant growth and pale green colouration of young leaves. Steffenson (1954) stated that height of shoot increased by sulphur application and he attributed this to the stimulatory effect of sulphur in cell division. Importance of sulphur in cell division, cell elongation and setting of cell structure was also reported by Stuckmeyer and Widdin (1958). Sulphur application is reported to enhance the chlorophyll synthesis in mustard (Singh and Singh, 1983). Upasani and Sharma (1986) found that application of sulphur @ 60-90 kg ha¹ significantly increased plant height of mustard however; Singh and Saran (1987) reported 30 kg S ha¹ to be effective in augmenting the plant height of mustard. Similar findings were also observed by Prasad et al. (1991). Where as Khanpara et al. (1993) working on B. juncea cv. Kranti reported that 100 kg S ha¹ enhanced the plant height.

Upasani and Sharma (1986) found
that 60-90 kg S ha\(^{-1}\) significantly increased number of leaves plant\(^{-1}\) and leaf area index of mustard. Sharma et al. (1990) reported that application of sulphur up to 80 ppm increased leaf chlorophyll content. Prasad et al. (1991) noted that sulphur application @ 30 kg S ha\(^{-1}\) through pyrite increased leaf plant\(^{-1}\). Khanpara et al. (1993) found that application of elemental sulphur or gypsum significantly increased leaf area index and chlorophyll 'a' and 'b' contents in the leaves of *Brassica juncea* cv. Kranti. Pradhan and Sarkar (1993) observed that application of 20 kg S ha\(^{-1}\) significantly increased leaf area index and crop growth rate (CGR) of rapeseed at flowering; however, Jain et al. (1995) reported that leaf area and CGR improved markedly up to 75 kg S ha\(^{-1}\). Khanpara et al., (1993) observed that sulphur application @ 50-200 kg S ha\(^{-1}\) increased primary and secondary branches plant\(^{-1}\) of *Brassica juncea* cv. Kranti. Dry matter production of mustard significantly increased due to sulphur application (Upasani and Sharma, 1986; Singh and Sahu, 1986; Mehta and Singh, 1988; Prasad and Singh, 1989; Rathore and Manohar, 1989; Sharma et al., 1990 and Mohan and Sharma, 1992). Gill and Palaskar (1992) in a pot culture experiment observed that *Brassica compestris* produced highest green fodder yield with application of 50 ppm N + 25 ppm P\(_2\)O\(_5\) + 25 ppm K\(_2\)O + 40 ppm sulphur through gypsum which was 51.3 per cent higher than NPK without sulphur. De and Nad (1993) observed that application of 45 kg S ha\(^{-1}\) significantly increased dry matter production of mustard. Dhankar et al. (1993) reported that dry matter production increased with increasing rate of sulphur application up to 60 ppm in both shoot and root. Similarly, Dubey and Khan (1993) and Chandel et al. (2002) also reported that 30 kg S ha\(^{-1}\) increased dry matter production of mustard over control.

Effect on Yield Attributes and Yield

Oilseed crops are rich in energy compounds such as oils and proteins. The sulphur has special function in the metabolism of oil synthesis as it promotes the formation of saturated fatty acids. Seed and oil yields are greatly enhanced by sulphur use (Kiepa, 1950). In general, sulphur application 30-100 kg ha\(^{-1}\) has been found beneficial under different agro-ecological conditions of the country with respect to mustard. Joshi et al. (1973) reported that sulphur application @ 50 kg ha\(^{-1}\) increased seed and stover yields of mustard, whereas Singh and Bairathi (1980) reported that the seed yield of mustard increased significantly with increasing levels of sulphur application up to 60 kg ha\(^{-1}\). Pods plant\(^{-1}\), 1000 seed weight as well as seed yield of mustard increased with increasing levels of sulphur application up to 60 kg ha\(^{-1}\) (Singh and Saran, 1987; Singh et al., 1988; Trivedi et al., 1995; Solanki et al., 1998; Singh et al., 1998; Mahapatra et al., 1999; Patel and Shelke, 1998) and oil yield (Saran and Giri, 1990). Aulakh et al. (1980) found that combined applications of 90 kg N and 60 kg S ha\(^{-1}\) gave maximum yield of *Brassica compestris* as well as *Brassica juncea*. Pathak and Tripathi (1979) obtained increased (20%) seed yield of rapeseed from 15.6 to 18.7 q ha\(^{-1}\) with the application of 80 kg S ha\(^{-1}\). Likewise Ankineedu et al. (1983) also recorded 18 per cent (16.0 to 18.9 q ha\(^{-1}\)) increase in seed yield of mustard with addition of 30 kg S ha\(^{-1}\) under rainfed conditions. Shukla et al. (1983) also obtained 9 per cent more yield (13.7 to 14.9 q ha\(^{-1}\)) with 20 kg S ha\(^{-1}\) than control. Increased mustard seed yield due to sulphur application has also been reported by Chatterjee et al. (1985); Chaudhury and Sharma (1986) and Singh et al. (1986). In term of yield Mazid (1986) reported highest response of sulphur in mustard (45%) compared to rice and wheat. Sawarker et al. (1987) revealed that mustard seed yield increased up to 40 kg S ha\(^{-1}\) but it declined slightly at higher rate of 60 kg S ha\(^{-1}\).

Giri and Saran (1987) stated that sulphur
application to mustard increased the total biomass and seed yield. Tiwari (1989) reported that mustard seed yield increased (14%) from 15.96 to 18.56 q ha\(^{-1}\) with 30 kg S ha\(^{-1}\) over control and the response ratio was 9.0 at 30 kg S ha\(^{-1}\). Rathore and Manohar (1989) also found that sulphur application up to 80 kg S ha\(^{-1}\) increased siliquae plant\(^{-1}\) (No.), 1000 seed weight and seed yield. According to Nepalia (1990), application of 25 kg S ha\(^{-1}\) to toria increased test weight and seed yield. However, Desai \textit{et al.} (1991) reported that yield and quality of \textit{Brassica juncea} remained unaffected by applied sulphur probably because 84 kg S ha\(^{-1}\) was supplied through irrigation water. Singh \textit{et al.} (1991) reported that seed yield of mustard increased with increasing pyrite application up to 500 kg ha\(^{-1}\). Seed yield of mustard increased with varying levels of sulphur application in different agro-climatic zones of the country (Mohan and Sharma, 1992; Mahapatra and Chandrakar, 1992; Sharma \textit{et al.}, 1992 Nepalia and Saroha, 1992; Dubey and Khan, 1993; Khanpara \textit{et al.}, 1993; Jain \textit{et al.}, 1995). In a pot trial on mustard, Lakdhani and Abrol (1992) obtained 20.4 g plant\(^{-1}\) seed yield with 60 kg S ha\(^{-1}\) as against 17.0 g under control. Narang \textit{et al.} (1993), Sahadev and Saran (1993) and Rajput \textit{et al.} (1993) also observed that seed yield of toria and mustard were lucrily improved with 20-50 kg S ha\(^{-1}\) in alluvial soil. Increase in seed yield of rape and mustard due to sulphur application from 20 to 60 kg ha\(^{-1}\) has also been reported by Patgiri and Baruah (1993); Pradhan and Sarkar (1993) and Golakiya and Polara (1993). Dubey \textit{et al.} (1994) observed response of sulphur upto 50 kg ha\(^{-1}\) and seed yield increased to the extent of 30.4 and 44.1 per cent over control respectively during the two years of experimentation due to 30-50 kg S ha\(^{-1}\). Increased seed yield of \textit{Brassica compestris} has also been obtained by various oilseed workers (Jaggi, 1994; Arora \textit{et al.} 1994; Sharma \textit{et al.} 1994 and Sen and Chatterjee, 1994). Similarly, under different agro-climatic conditions, responses of sulphur upto 45 kg ha\(^{-1}\) were observed for toria (Das and Das, 1995); for \textit{B. napus} (Kumar, 1995) and up to 30 kg ha\(^{-1}\) for mustard cv. Varuna (Kharbade \textit{et al.}, 1995). Jain \textit{et al.} (1996) in Rajasthan noticed increase in seed yield of \textit{B. juncea} cv. T-59 from 1.40 to 1.55 t ha\(^{-1}\) with 75 kg S ha\(^{-1}\) against no sulphur. Singh and Sharma (1996) found that branches number, siliquae plant\(^{-1}\), seeds siliqua\(^{-1}\), 1000 seed weight as well as seed and stover yield increased with increasing sulphur levels upto 45 kg S ha\(^{-1}\). Bhagwan \textit{et al.} (1996) also noticed increased seed yield of \textit{B. juncea} cv. NDR 8501 upto 40 kg S ha\(^{-1}\). However, Purakayastha and Nad (1996) reported decline in seed yield of mustard cv. Pusa Bold with increasing sulphur levels upto 90 kg ha\(^{-1}\). According to observations of Kachroo and Kumar (1997) branch number, siliquae plant\(^{-1}\), seeds siliqua\(^{-1}\), 1000 seed weight and their additive effect influenced seed yield of Indian mustard cv. Kranti upto 40 kg S ha\(^{-1}\). Mahal \textit{et al.} (1997) and Chandel \textit{et al.} (2002) obtained higher seed yield of mustard upto 30 kg S ha\(^{-1}\). Jaggi (1998) and Ahmad \textit{et al.} (1998) also recorded similar observations. However, mustard cv. Kranti responded only upto 20 kg S ha\(^{-1}\) (Khan and Hussain, 1999).

**Effect on Quality**

Sulphur plays an important role in improving the quality and marketability of produce. The quality decides the market price and output of the end product i.e. oil per unit of economic yield. Aulakh \textit{et al.} (1980) obtained 6 per cent more oil content and 0.7 q ha\(^{-1}\) more oil yield in raya with the application of 60 kg S ha\(^{-1}\) than control. Similar, observation has also been reported by Singh (1984) and Upasani and Sharma (1986). However, Singh and Sahu (1986) obtained 7.3 per cent higher oil content of rapeseed with @ 45 kg S ha\(^{-1}\) over control. Favorable effect on seed oil
content was also reported by Singh et al., 1988) and 45 kg ha\(^{-1}\) (Sawarker et al., 1987). They concluded that increase in oil content was due to higher synthesis of glucoside. Similar findings have also been reported by Verma and Sawarker (1988); Rathore and Manohar (1989), Nepalia (1990), Narwai et al. (1991), Singh et al. (1991) and Jain and Saxena (1991). Walker and Booth (1994) reported that sulphur application increased glucosinolate content in mustard seed. Arora et al. (1994) found that increasing levels of sulphur from 0 to 60 kg ha\(^{-1}\) increased allyl isothiocyanate content in seeds of mustard. Shukla et al. (1983) found that seed protein content of rai improved significantly by sulphur application @ 20 kg ha\(^{-1}\). Similar results have also been reported by Singh et al. (1986); Sawarker et al. (1987); Singh et al. (1991); Narang et al. (1993); Dubey et al. (1994), Trivedi et al. (1995) and Chandel et al. (2002).

**Effect on Nutrient Uptake**

**Nitrogen:** Sulphur plays an important role in reduction of nitrate and nitrogen metabolism of plants. It also increases the chlorophyll content of leaf, which has nitrogen as a constituent and thus an increase in nitrogen concentration by sulphur application is likely. Aulakh et al. (1980) reported that application of sulphur increased nitrogen content and uptake in Indian mustard. Application of 50 ppm sulphur resulted in higher nitrogen content and uptake (Singh et al., 1988). Jain et al. (1995) noticed that phosphorus uptake in seed and stover of mustard cv. T-59 increased with application of sulphur @ 75 kg ha\(^{-1}\).

**Phosphorus:** In general, phosphorus and sulphur interaction is synergistic at lower to medium levels of phosphorus and antagonistic only at higher levels, usually at 60 kg or higher doses of P\(_2\)O\(_5\) ha\(^{-1}\). However, in calcareous and high pH soils, acid forming sulphur sources may increase phosphorus availability by lowering soil pH. In soybean, interaction between phosphorus and sulphur was synergistic at 35 kg P ha\(^{-1}\) but antagonistic at 52.5 kg P ha\(^{-1}\) (Aulakh et al., 1985). Application of 50 ppm S resulted in higher phosphorus content and uptake of mustard (Singh et al., 1988). Jain et al. (1995) noticed that phosphorus uptake in seed and stover of mustard increased with application of sulphur @ 75 kg ha\(^{-1}\).

**Potassium:** Increase in potassium uptake mainly due to increase in yield of mustard by sulphur application @ 60 kg ha\(^{-1}\) has been reported by Singh et al. (1988) and Tandon (1991). Sharma et al. (1992) reported that the application of 30 kg S ha\(^{-1}\) increased potassium uptake by mustard seed and stover over control. Kumar (1995) and Srivastava and Srivastava (1996) also observed that increasing sulphur levels increased potassium uptake by mustard.

**Sulphur:** Joshi et al. (1973) found that sulphur application to mustard increased sulphur content in plant at 60 days after sowing and at harvest. The sulphur content of plants increased upto 50 kg S ha\(^{-1}\) but S application @ 75 kg ha\(^{-1}\) showed decreasing trend. Aulakh et al. (1977) also noticed increase in plant sulphur content at vegetative growth stages due to the application of 60 kg S ha\(^{-1}\). Singh and Baira (1980) and Dev et al. (1981) found that sulphur application to mustard increased
sulphur uptake, however, sulphur content in shoot tended to decrease with increasing plant age (Singh and Singh, 1984). Application of sulphur to mustard results in higher sulphur content in its seeds (Singh et al., 1988) and its content increases in shoot at rosette and flowering stages (Sharma et al., 1990) and (Bahl et al., 1990). Jain et al. (1984) reported that a mustard crop producing 25.96q ha$^{-1}$ removed 44.9 kg S ha$^{-1}$ and mustard crop yielding 20q ha$^{-1}$ removed 32.0 kg S ha$^{-1}$ and the critical concentration of sulphur in rapeseed and mustard plant at flowering was 0.18 per cent in whole plant (Tandon, 1991). Working on mustard, Sharma and Kamath (1991) observed that increasing levels of sulphur application upto 90 kg ha$^{-1}$ resulted in corresponding increase in sulphur uptake. However, the sulphur utilization decreased from 15.6 to 13.2 per cent when sulphur application increased from 45 to 90 kg ha$^{-1}$. De and Nad (1993) also observed increase in sulphur uptake at 30 and 60 DAS by mustard cv. Pusa Bold upto 50 and 60 per cent with application of 45 and 90 kg S ha$^{-1}$, respectively over control. Increase in sulphur content of mustard with increasing sulphur levels has also been reported by Sharma et al. (1994); Chakraborty et al. (1994) and Chauhey and Dwivedi (1995). Kumar (1995) reported that sulphur concentration in plants of B. napus increased by increasing levels of sulphur application upto 60 kg ha$^{-1}$, whereas Jain et al. (1995) noticed increased sulphur uptake both in seed and stover of B. juncea cv. T-59 with sulphur application upto 75 kg ha$^{-1}$. Similarly, Jain et al. (1996) and Purakayastha and Nad (1996) also reported significantly higher sulphur uptake by mustard with increasing levels of sulphur application upto 75 and 90 kg ha$^{-1}$, respectively.

**Apparent Recovery**

Yadav et al. (2000) reported that sulphur use efficiency varied form 8.0 to 19.6 per cent in rice, with maximum at 15 kg S ha$^{-1}$. Highest agronomic use efficiency of 15.9 kg grain kg$^{-1}$ S was recorded at low S level of 15 kg ha$^{-1}$. The cumulative effect of sulphur on rice-mustard cropping sequence showed maximum agronomic efficiency and S-recovery at 30 kg S ha$^{-1}$. The maximum value cost ratio was found at 15 kg S ha$^{-1}$ in rice and 30 kg S ha$^{-1}$ in mustard. Apparent recovery of S in groundnut-wheat and groundnut-mustard cropping systems varied with different levels of S application. Sulphur recovery from added S improved with increasing levels of S upto 30 kg ha$^{-1}$. Further increase in the S level (45 kg ha$^{-1}$) resulted decrease in sulphur recovery under both the cropping systems. As regard agronomic efficiency of S, crop response in term of kg grain kg$^{-1}$ S ranged from 4.4 to 12.6 in groundnut and 9.5 to 14.3 in wheat. In groundnut-mustard cropping system, it varied from 4.0 to 4.8 in groundnut and 5.3 to 7.3 in mustard with added S levels ranging from 15 to 45 kg ha$^{-1}$ (Sarkar et al., 2000). The higher agronomic efficiency at higher sulphur doses may be associated with more residual value of sulphur at 45 kg ha$^{-1}$. In case of soybean agronomic efficiency was highest (50 kg ha$^{-1}$) at 30 kg S ha$^{-1}$. Apparent sulphur recovery increased with increasing S levels in groundnut but decreased with increasing sulphur levels in sunflower (Malewar et al., 2000).

**Residual Effect of Sulphur Application**

The residual effects of sulphur applied to rice on succeeding crops of wheat, mustard, green gram, okra and cotton have been reported. The response has been found to vary from 3 to 19 per cent in wheat as compared to 9-22 and 11-24 per cent in mustard and cotton, respectively. The residual effect was much higher in green gram (15-101%) and okra (43-82%). The increase in mustard seed yield due to residual sulphur was higher in rice-mustard cropping system than that observed in groundnut-mustard cropping system. Yield
gains from sulphur application on rice-wheat cropping system increased with the increase in rate of sulphur application. The average increase in yield was 11, 22 and 28 per cent while the response ratio was 54, 53 and 45 at 15, 30 and 45 kg S ha\(^{-1}\) respectively (Sarkar, 2000). Residual effect of sulphur applied to groundnut was evident on succeeding wheat and mustard crops up to 45 kg ha\(^{-1}\). An increase in average grain yields of wheat and mustard by 430 and 270 kg ha\(^{-1}\), respectively over control was recorded at this level. Residual effect of S was more pronounced at higher level of S than that at lower levels. Yadav et al. (2000) and Singh et al. (2002) while studying the response of sulphur in rice-mustard cropping system found that application of sulphur to rice crop had positive effect on the yields and yield attributing characters of the system. In rice, the plant height, tiller number m\(^{-2}\) and grains panicle\(^{-1}\) increased by applying sulphur up to 45 kg ha\(^{-1}\). The residual effect of sulphur on mustard revealed that the values of yield attributing parameters increased appreciably only up to 30 kg ha\(^{-1}\). The cumulative effect in terms of rice equivalent yield of the rice-mustard cropping system also showed that yield increased markedly up to 30 kg S ha\(^{-1}\). It increased by 8.5 and 17.1 per cent over control at 15 and 30 kg S ha\(^{-1}\), respectively.

REFERENCES